

Some Effects of Forest Harvesting on
Water Quality in the Slim Creek Watershed
in the Central Interior of British Columbia

M.J. Brownlee, B.G. Shepherd, and D.R. Bustard

Department of Fisheries and Oceans
Habitat Management Division
555 West Hastings Street
Vancouver, British Columbia V6B 5G3

Canadian Technical Report of
Fisheries and Aquatic Sciences
No. 1613

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 901-1425 were issued as Manuscript Reports of the Fisheries Research Board of Canada. Numbers 1426-1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Science 1613

May 1988

SOME EFFECTS OF FOREST HARVESTING ON
WATER QUALITY IN THE SLIM CREEK WATERSHED
IN THE CENTRAL INTERIOR OF BRITISH COLUMBIA

by

M.J. Brownlee, B.G. Shepherd, and D.R. Bustard¹

Department of Fisheries and Oceans
Habitat Management Division
555 West Hastings Street
Vancouver, British Columbia V6B 5G3

¹D. Bustard and Associates, Box 2792, Smithers, B.C. V0J 2N0

Minister of Supply and Services Canada 1988

Cat. No. Fs 97-6/1613E

ISSN 0706-6457

Correct citation for this publication:

Brownlee, M.J., B.G. Shepherd, and D.R. Bustard. 1988. Some effects of forest harvesting on water quality in the Slim Creek watershed in the central interior of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1613: 41p.

CONTENTS

Abstract/Résumé.....	iv
Preface.....	vi
Introduction.....	1
Study objectives.....	1
Study area description.....	1
Logging practices in study area.....	3
Methods.....	3
Study design.....	3
Water quality parameters measured.....	5
Results.....	6
Precipitation.....	6
Discharge.....	6
Suspended sediment.....	7
Water temperature.....	16
Dissolved oxygen.....	18
Stream nutrients.....	20
Discussion.....	27
Suspended sediment.....	27
Water temperature.....	29
Stream nutrients.....	30
Management implications.....	31
References.....	34
Appendix 1.....	37

ABSTRACT

Brownlee, M.J., B.G. Shepherd, and D.R. Bustard. 1988. Some effects of forest harvesting on water quality in the Slim Creek watershed in the central interior of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1613: 41p.

The effects of forest harvesting practices on water quality were examined within a watershed 80 km east of Prince George in the central interior of British Columbia between 1971 and 1975. Suspended sediment loading in the study stream, Centennial Creek, increased 4 to 12 times over corresponding levels in an adjacent control stream. Mainline road development was the main source of increased levels of sediment which persisted for the duration of the three years of study. At associated tributaries, erosion from skid trails, landings, road crossings and streambank damage occurred during and after logging, but in contrast, it did not persist beyond the first summer after logging. Mean water temperatures increased 1 to 3 C following logging to the edge of small tributary streams. Diurnal fluctuations more than doubled. Although maximum water temperatures in these small streams increased up to 9 C they remained within tolerance levels for salmonids. When instream nutrients were at high levels, logged areas had 1-2 times the orthophosphate concentrations, 2-3 times the total phosphate concentrations, and up to 5 times the nitrate concentrations present in the unlogged watershed.

The implications of this study's results to forest harvesting operations in the interior of British Columbia are discussed.

RÉSUMÉ

Brownlee, M.J., B.G. Shepherd, and D.R. Bustard. 1988. Some effects of forest harvesting on water quality in the Slim Creek watershed in the central interior of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1613: 41p.

Entre 1971 et 1975, on a étudié les effets de certaines méthodes d'exploitation forestière sur la qualité de l'eau d'un bassin versant situé à 80 km à l'est de Prince George dans la partie intérieure centrale de la Colombie-Britannique. La quantité de sédiments en suspension dans le cours d'eau traité a augmenté de 4 à 12 fois par rapport aux niveaux correspondants observés dans un cours d'eau témoin. Les niveaux accrus, principalement attribué à la construction de routes principales, ont persisté pendant les trois années qu'a duré l'étude. Dans les tributaires situés en amont il y a eu dommages aux berges et érosion provenant des pistes de débordage, des jetées et traverses de chemins, mais cela n'a pas persisté au-delà du premier été après l'exploitation. A la suite de coupes jusqu'en bordure des petits tributaires, il y a eu augmentation de température moyenne de l'eau, de 1 à 3 C. Les fluctuations diurnes ont plus que doublé. Bien que les températures maximales de l'eau dans ces petits cours d'eau aient augmenté jusqu'à 9 C, elles sont restées dans les limites de tolérance établies pour les salmonidés. Lorsque les substances nutritives dans les cours d'eau étaient à des niveaux élevés, les secteurs exploités avaient de 1 à 2 fois les concentrations d'orthophosphates, 2 à 3 fois les concentrations de phosphate total et jusqu'à cinq fois les concentrations de nitrates présentes dans la partie non exploitée du bassin versant.

On discute des implications de ces résultats sur les activités d'exploitation forestière à l'intérieur de la Colombie-Britannique.

PREFACE

A study of forest harvesting effects on water quality and fish habitat was conducted in the Slim-Tumuch watershed in the central interior of British Columbia from 1971 to 1975. Many of the study results outlining the effects of forest harvesting on fish spawning and rearing habitat, physical alteration of small stream channels following logging, and downstream effects on a small lake were published in 1977. However, the results of the water quality component of the study remained in a draft format, waiting to be incorporated into an overall compendium of study results. This compendium was never completed. As a result, the water quality information has not been readily accessible to potential users such as resource agency personnel and industrial foresters.

The Slim-Tumuch study is the only detailed work in the interior of British Columbia that has evaluated the effects of forest harvesting on streams. The need to make the study results more available has gained importance with the recent introduction of Coastal Fisheries Forestry Guidelines and the future possibility of developing a corresponding set of guidelines for interior logging practices. The information in this report contributes to our understanding of how small northern interior British Columbia streams respond to forest harvesting practices. While some of the references are outdated, and a new emphasis on stream morphology factors has developed in the 1980's, the water quality results help provide an understanding of a small watershed's response to forest harvesting.

Following a workshop and field trip to this watershed in September 1987, a group of forestry and fisheries resource managers recommended the publication of all information from the Slim-Tumuch study that was not already published. As a result, a contract was provided to David Bustard and Associates to complete the water quality report to a level suitable for publication in the Technical Report Series for the Department of Fisheries and Oceans.

It is worthwhile to note that during the September 1987 field trip, the researchers who had conducted the original studies in the Slim Creek watershed suggested that some major morphological changes had occurred in the smaller study streams since their work ended in the mid-1970's. For example, they noted that large organic debris and gravels present in upper Karolyn and Rosanne creeks during their studies appeared to have shifted into the lower reaches of these two streams. It was suggested that detailed follow-up measurements of these stream channels would provide valuable long-term indications of the extent of changes that might occur in small interior mountain streams following logging.



INTRODUCTION

STUDY OBJECTIVES

In British Columbia there is little information on the effects of forest harvesting practices on streams and lakes in the interior of the province. Fisheries managers have assessed the potential impacts of proposed logging operations by applying the results of studies conducted in coastal British Columbia, Washington, Oregon and Alaska. This approach was frequently questioned by forestry and fisheries managers because interior conditions differ markedly in climate, flow regime, soils, and logging methods. Accordingly, both resource agencies and forest companies recognized the need for short-term studies that would generate guidelines applicable to interior conditions.

In 1971 a study was initiated by the federal Fisheries and Marine Service (now the Department of Fisheries and Oceans), and the provincial Department of Recreation and Conservation (now the Ministry of Environment and Parks) to provide information on the possible effects of forest harvesting practices on water quality and fish habitat. The principal study objective was to assess the effectiveness of fish habitat protection measures incorporated into 1971-72 cutting permits within a watershed, Slim Creek, typical of the interior area of British Columbia.

Specific objectives of this study were to assess the effects of road construction and different logging practices on suspended sediment, water temperature, dissolved oxygen, and nutrient levels within the Slim Creek watershed. The study provided an opportunity to measure water quality changes downstream from the operations and to compare them to a nearby undisturbed watershed. A series of technical reports outlining the effects of forest harvesting on fish spawning and rearing habitat (Slaney et al. 1977a and b), physical alteration of small stream channels (Slaney et al. 1977c), and on the limnology of a downstream lake (Parkinson et al. 1977) are reported elsewhere.

STUDY AREA DESCRIPTION

Study streams were located in the Slim Creek (Centennial, Rosanne, Karolyn and Leaner creeks) and Bowron River (Hee Creek) watersheds, 80 km east of Prince George (Figure 1). Field measurements were largely limited to Slim Creek upstream of Tumuch Lake including Centennial and Donna creeks with watershed areas of 44 km² and 42 km² respectively. Owing to a waterfall obstruction no fish species were resident in Centennial Creek and its tributaries, Rosanne and Karolyn creeks, until stocked in 1972 and 1973.

Soils in the study area are diverse and range from sorted

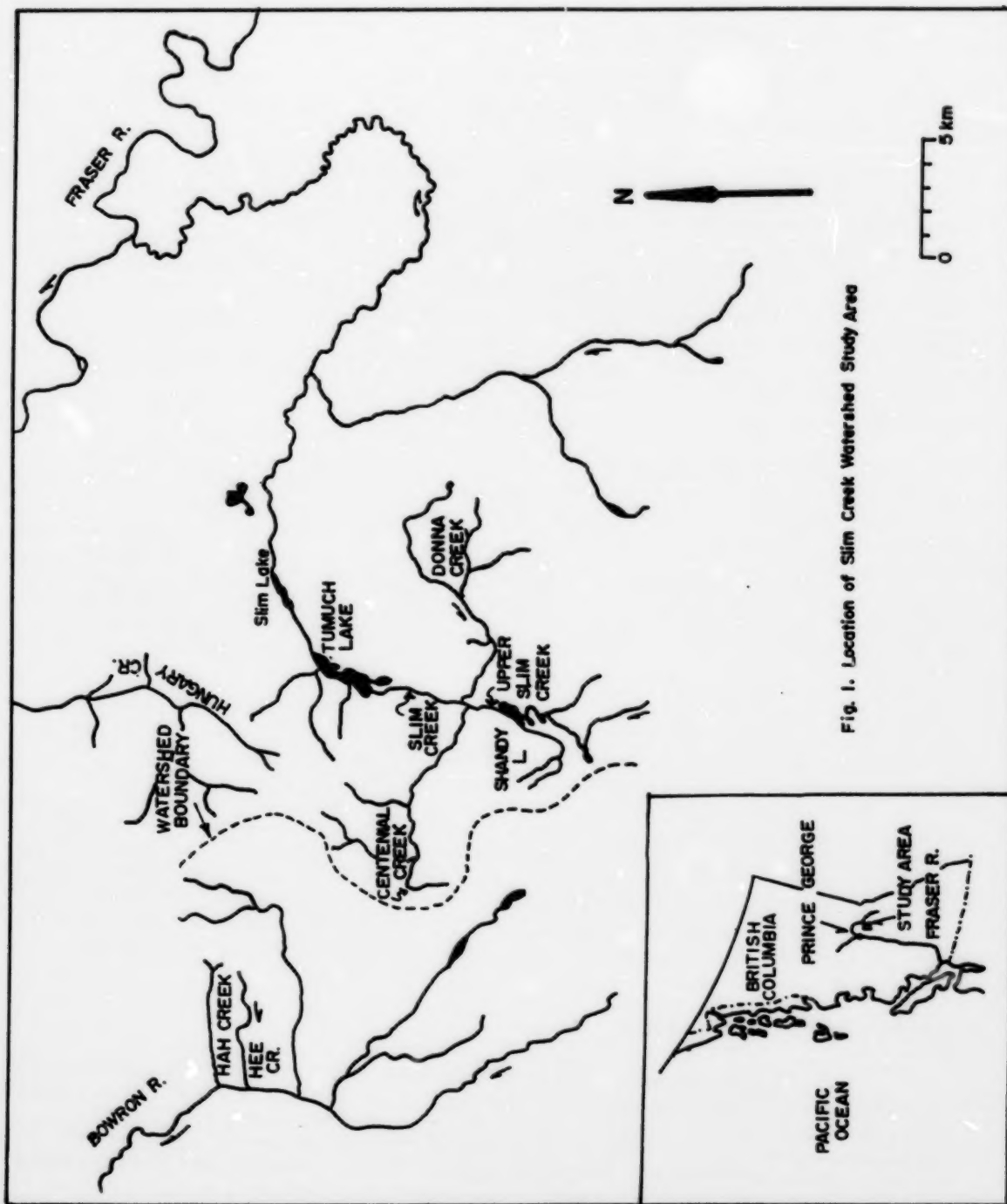


Fig. 1. Location of Slim Creek Watershed Study Area

sandy gravels and silty loam on the valley bottoms, silty loam terraces in some valley side walls, and poorly sorted ablation tills on most slopes. Slopes in the logged areas ranged from 20-30% on the sidehills to near level in the valley bottoms. The forest cover is predominantly white spruce (Picea glauca), subalpine fir (Abies lasiocarpa) and western red cedar (Thuja plicata).

LOGGING PRACTICES IN STUDY AREA

Road construction was initiated during autumn 1971 at the upstream margin of the Centennial Creek watershed. Standard road building practices were utilized, clearing a 30 to 45 m opening, using local road materials for the subgrade, and installing steel pipe culverting at the watercourses. Haul roads were more than 100 m from the streams except at crossing locations. Secondary roads and landings were pre-located on cutting permit plans, but skidtrail layouts were largely left to the judgment of logging contractors. Whole trees were skidded to landings for bucking, sorting, and loading. Clearcutting of 120 ha cutting units was conducted in the sequence shown in Figure 2. Adjacent to main streams (Slim and Centennial) conifer plus deciduous reserve strips of variable width were left standing. Practices near tributary streams, Rosanne and Karolyn creeks, ranged from extensive instream felling and skidding (non-directional practice) during winter logging in the lower reaches, to largely felling and skidding away from channels (directional practice) during the summer in the upper reaches.

METHODS

STUDY DESIGN

A total of 16 stations were established to monitor water quality conditions within the study streams (Figure 2). The water quality program was designed to make simultaneous comparisons between logged and unlogged streams, and within discrete stream reaches of logged streams. The sampling design was intended to provide the following features:

- a.) The cumulative effect of forest harvesting on streams was compared using data collected at the downstream end of logged Centennial Creek (Station 10) and data from unlogged Slim and Donna creeks (Station 11 and 12).
- b.) The effects of different timing and type of logging activity on water quality were monitored in Centennial, Hee, and Leaner creeks.
- c.) The recovery rate at sites in the inlet and outlet of Tumuch Lake (Stations 13 and 15), were compared to upstream stations in the logged and unlogged watersheds.

FIGURE 2. Cutting Units and Sampling Stations in the Upper Slim-Tumuch Watershed.



d.) As well, stream water quality recovery over time following logging was monitored at Stations 2, 2A, 6, 9 and 10.

WATER QUALITY PARAMETERS MEASURED

Water quality parameters monitored at the stations included measurements of suspended sediment, water temperature, surface and sub-gravel dissolved oxygen, nutrients and total dissolved solids (TDS). All parameters were related to stream discharge.

Suspended Sediment

Depth integrated sampling of suspended sediment was conducted with a USDH-48 sampler. Standard analysis for non-filtrable residue accurate to 5 mg/l (Taras et al. 1971) using a 1.2 micron Sartorius membrane filter was conducted at a field laboratory. Owing to difficult access, sampling frequency was intermittent in 1972. However, in 1973, midstream samples were taken every two days at Stations 1, 2, 2A, 3, 3A, 4, 6, 9, 10, 11, and 12. Stations 13, UH and LH (upper and lower Hee Creek), and UL and LL (upper and lower Leaner) were sampled on a weekly basis. Station 14 was added to the sampling program during the spring snowmelt period of 1974. Diurnal and cross-sectional variations in sediment loads were examined periodically at Stations 6, 9, 10, and 12.

Water Temperature

Taylor maximum-minimum thermometers calibrated to an Ertco calibration thermometer were installed at Stations 1, 2A, 3A, 4, 6, 9, 10, 11, and 12. Readings were taken at the same time as suspended sediment samples in 1972 and 1973. During 1973, two-probe Weksler thermographs were installed at Stations 1 and 2A to monitor mid-summer and winter surface and sub-gravel water temperatures. As well, Ryan thermographs were installed in Hee Creek (UH and LH) during 1973 and 1974.

Dissolved Oxygen

The Hach modification of the idiometric method (accurate to 0.1 ppm) was used to measure dissolved oxygen. Surface dissolved oxygen samples were collected weekly at all stations in 1973. No dissolved oxygen sampling was conducted in 1974. Subgravel oxygen samples (20 cm depth) were taken with a 634 ml stainless steel syringe. This sampling was conducted in conjunction with an assessment of egg survival at gravel sites (Slaney et al. 1977a).

Nutrients

Water samples for nutrient analyses were collected at all

stations in 1972 at weekly to monthly intervals. Sampling continued at weekly intervals in 1973, and bi-weekly intervals in 1974 as road access improved in the study area. Samples were collected in plastic one-liter bottles for analysis of individual constituents and preserved with 5 ml of chloroform. As well, half-liter samples were collected for TDS measurements and preserved with 1 ml of dilute copper sulfate solution. All samples were frozen immediately and shipped to the Cypress Creek Laboratory for standard analyses of orthophosphate, total phosphate, nitrate, nitrite, ammonia, and TDS.

Stream Discharge

Chain or staff gauges installed at Stations 2, 3, 6, 9, 10, 11, and 12 were read periodically in 1972 and three times a week in 1973 and 1974. Flows at these stations were measured at various stages with a Gurley meter to establish stage-discharge calibration curves. Discharge was recorded on a continuous basis at Stations 10 and 12 using Stevens Type F recorders.

Air Temperature, Precipitation, and Solar Radiation

Air temperatures at Karolyn Camp were recorded daily using a Taylor maximum-minimum thermometer. Precipitation was measured using a rain can in 1972 and a Belfort universal rain gauge (hourly readings) in 1973 and 1974. A Belfort recording pyrheliometer was used periodically throughout the study to measure solar radiation.

RESULTS

PRECIPITATION

Precipitation in the study area averages approximately 100 cm annually and is equally divided between rain and snow. The study area is colder and averaged approximately 40% more precipitation than the permanent weather station located in Prince George (Table 1). Total snowfall was above average in 1972 and 1974, and less than average in 1973. The winter of 1973 was mild, with spring break-up arriving 2 and 4 weeks earlier than in 1972 and 1974 respectively. A summary of the rainfall measurements from the study area is presented in Figure 3.

DISCHARGE

Streamflows in the study area peak in the spring with a second peak in autumn and are lowest in the winter (Figure 3). In 1973 and 1974 Centennial and Donna creeks peaked in May and June at 6 to 8 m³/sec, decreased to 0.7 m³/sec by mid-summer and approximately 0.35 m³/sec in the winter. Flows in Rosanne Creek peak at 1.1 to 1.4 m³/sec in May and June, decreasing to 0.1 to 0.2 m³/sec during the summer.

Table 1. Selected Weather Information from Karolyn Creek Camp and the Prince George Airport.

A. Total Precipitation (cm) During the Study Periods

<u>Period</u>	<u>Karolyn Camp</u>	<u>Prince George</u> <u>(Study Period)</u>	<u>Prince George</u> <u>(Average)</u>
Jun-Oct 1972	38	33	30
Apr-Nov 1973	64	41	43
May-Jul 1974	36	23	15

B. Annual Snowfall (cm) at the Prince George Airport During Study Period

<u>Year</u>	<u>1971-72</u>	<u>1972-73</u>	<u>1973-74</u>	<u>Average</u>
	330	198	394	231

C. Mean Monthly Air Temperatures (C) During 1973

<u>Month</u>	<u>Karolyn</u>	<u>Prince George</u>
Apr	3	4
May	8	10
Jun	10	12
Jul	13	14
Aug	12	13
Sep	9	9
Oct	2	4
Nov	-13	-9

During the snowmelt freshet discharge in the streams can vary considerably within a single day. For example, Donna Creek flows (Station 12) doubled from 3.6 to 7.1 m³/sec during an 11-hour period on July 18, 1974.

SUSPENDED SEDIMENT

Highest suspended sediment loads were associated with the May and June snowmelt periods and with rainfall events in June, July and the October-November periods (Figure 3). Estimates of the monthly sediment loads were calculated from concentration and discharge measurements at each station. Sediment loading to lower Centennial Creek (Station 10) ranged from 1.1 to 1.7 million kg during the May to July measurement periods from 1972 to 1974 (Table 2). Sediment loading in the undisturbed Donna

FIGURE 3.
Precipitation, Suspended Sediment, and
Stream Discharge at Stations 10 (Centennial -
Logged) and Station 12 (Donna - Control)
1972 - 1974

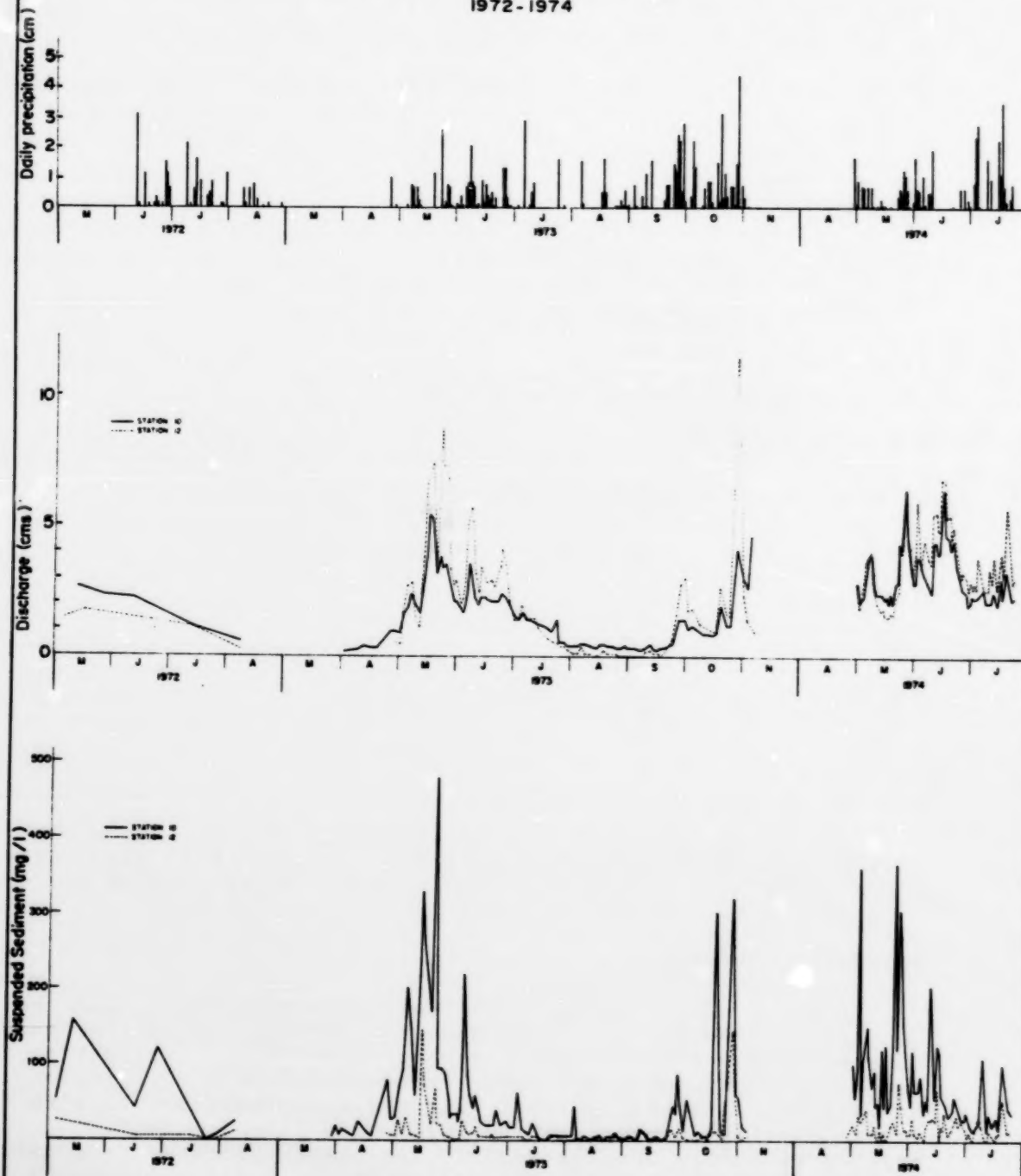


Table 2. Monthly Suspended Sediment Loads ($\text{Kg} \times 10^5$) at Selected Stations.

Year	1972	1973	1974	1972	1973	1974	1972	1973	1974
Month	Station 1 Upper Rosanne			Station 2A Centenial above Rosanne			Station 4 Lower Karolyn		
Apr	-	-	-	-	-	-	-	-	-
May	-	0.2	0.1	-	0.4	0.1	-	0.1	0.1
Jun	-	0.1	0.2	-	0.1	0.3	-	0.1	0.1
Jul	-	*	0.1	-	*	0.1	-	*	0.1
Aug	-	*	-	-	*	-	-	0.0	-
Sep	-	*	-	-	*	-	-	*	-
Oct	-	0.1	-	-	0.1	-	-	*	-
May-Jul	-	0.3	0.4	-	0.5	0.5	-	0.2	0.3

	Station 9 Centenial above Karolyn			Station 6 Top End Silt Banks			Station 10 Lower Centenial		
Apr	-	0.2	-	-	-	-	-	0.2	-
May	-	2.1	1.9	-	3.9	6.5	5.2	11.7	9.3
Jun	-	0.4	2.8	-	1.0	4.4	3.9	4.5	5.6
Jul	-	*	0.8	-	0.1	1.0	2.0	0.3	2.0
Aug	-	*	-	-	*	-	0.3	0.1	-
Sep	-	0.1	-	-	0.1	-	-	0.2	-
Oct	-	0.7	-	-	0.9	-	-	3.0	-
May-Jul	-	2.5	5.5	-	5.0	11.9	11.1	16.5	16.9

	Station 11 Upper Slim			Station 12 Donna Creek		
Apr	-	0.1	-	-	-	-
May	0.4	0.3	0.4	0.9	2.8	1.2
Jun	0.0	0.3	0.9	0.0	0.6	2.0
Jul	0.1	0.1	0.5	*	0.1	1.1
Aug	0.0	*	-	0.1	*	-
Sep	-	0.1	-	-	0.1	-
Oct	-	0.1	-	-	1.1	-
May-Jul	0.5	0.7	1.8	0.9	3.4	4.3

*=greater than 0 but less than 0.05

Creek (Station 12) ranged from 0.1 to 0.4 million kg during the same period. Sediment loads in the logged watershed were 4 to 12 times higher than those in the unlogged watershed, depending upon the year. The high sediment loading measured at Station 10 on lower Centennial Creek persisted for the duration of the study, indicating that short-term recovery was slight.

Suspended sediment levels decreased downstream of the confluence of Centennial and Slim creeks. Sampling just upstream of Tumuch Lake in Slim Creek indicated suspended sediment levels were approximately 20% of those at Station 10 in lower Centennial in 1973 and 1974 (Table 3). It is presumed that a combination of dilution of Centennial Creek water with clearer water from the unlogged watersheds (Slim and Donna creeks) and sediment deposition in the upper reaches accounted for the lower levels.

Suspended sediment levels at the outlet of Tumuch Lake for May to July 1974 averaged 9 mg/l with a maximum of 14 mg/l (Table 3). These levels were similar to those measured at an upstream control on upper Slim Creek (Station 11) which is also lake-headed. Parkinson et al. (1977) found that most of the suspended sediment entering Tumuch Lake settled out in the southern half of the Tumuch inlet basin.

Table 3. Mean and Maximum Suspended Sediment Concentrations (mg/l) at Sites Above and Below the Mainline Road Silt Banks on Centennial Creek and in Slim Creek Above and Below Tumuch Lake.

Treatment	Stn	Mean (Maximum) Suspended Sediment					
		1972		1973		1974	
		Melt	Post	Melt	Post	Melt	
<u>Centennial</u>							
Above	9	- (81)	9(18)	27(150)	11(172)	37(103)	
Top End	6	153(161)	15(30)	37(257)	16(143)	64(456)	
Below	10	88(160)		73(516)	29(322)	88(335)	
<u>Slim Creek</u>							
Above Centennial	11					12(20)	
Above Tumuch	13			29(154)		27(61)	
Below Tumuch						9(14)	

Sources of sediment transported to Centennial Creek and downstream to Slim Creek were primarily the main haul road and to a lesser extent skid trails, landings, and stream channels. Little erosion was evident from the loamy till and colluvial materials on the main road from Rosanne Creek to Karolyn Creek, but the remaining 5 km of road located in sloping deposits of silty loam contributed much of the sediment to Centennial Creek (Figure 4).

The subgrade was constructed during the winter. This augmented sediment movement to the stream since snow was mixed with soil on fill slopes causing road banks to slump and overland flow of sediment. Sediment from fills and from culverts leading from ditches at the base of cut slopes reached Centennial Creek via small drainages that traversed the reserve strips. At one large slope sediment was transported by overland flow for 100 m from the road including over 60 m of slope less than 1%.

The mean and maximum suspended sediment levels at sites above and below the silt banks during the three years of study are summarized in Table 3. The data indicates that suspended sediment levels more than doubled below the silt banks during the melt period in 1973, rising from an average of 27 mg/l at Station 9 to 73 mg/l at Station 10 in lower Centennial. However, the data is confounded by inputs from Karolyn Creek between Stations 9 and 10. Measurements taken at Station 6 are near the top end of where the mainline road transects the fine-textured silt materials (Figure 4).

Table 4 shows the increase in suspended sediment levels downstream of the silt banks during rainstorm events in September and October 1973. Suspended sediment levels increased 2 to 7-fold downstream of the silt banks during these storms, illustrating the dominant role of this section of road in contributing to increased sediment levels in Centennial Creek. This data is probably less representative of the overall suspended sediment levels than the data in Table 3 which represents averages over a longer time period.

Table 4. Suspended Sediment Levels (mg/l) in Centennial Creek Above and Below Silt Banks on the Mainline Logging Road During 1973 Autumn Rains.

<u>Date</u>	<u>Above Silt Banks</u>	<u>Below Silt Banks</u>	<u>Percentage Increase</u>
Sept 26	23	157	683
Sept 27	101	234	232
Oct 19	49	227	463
Oct 27	102	561	550

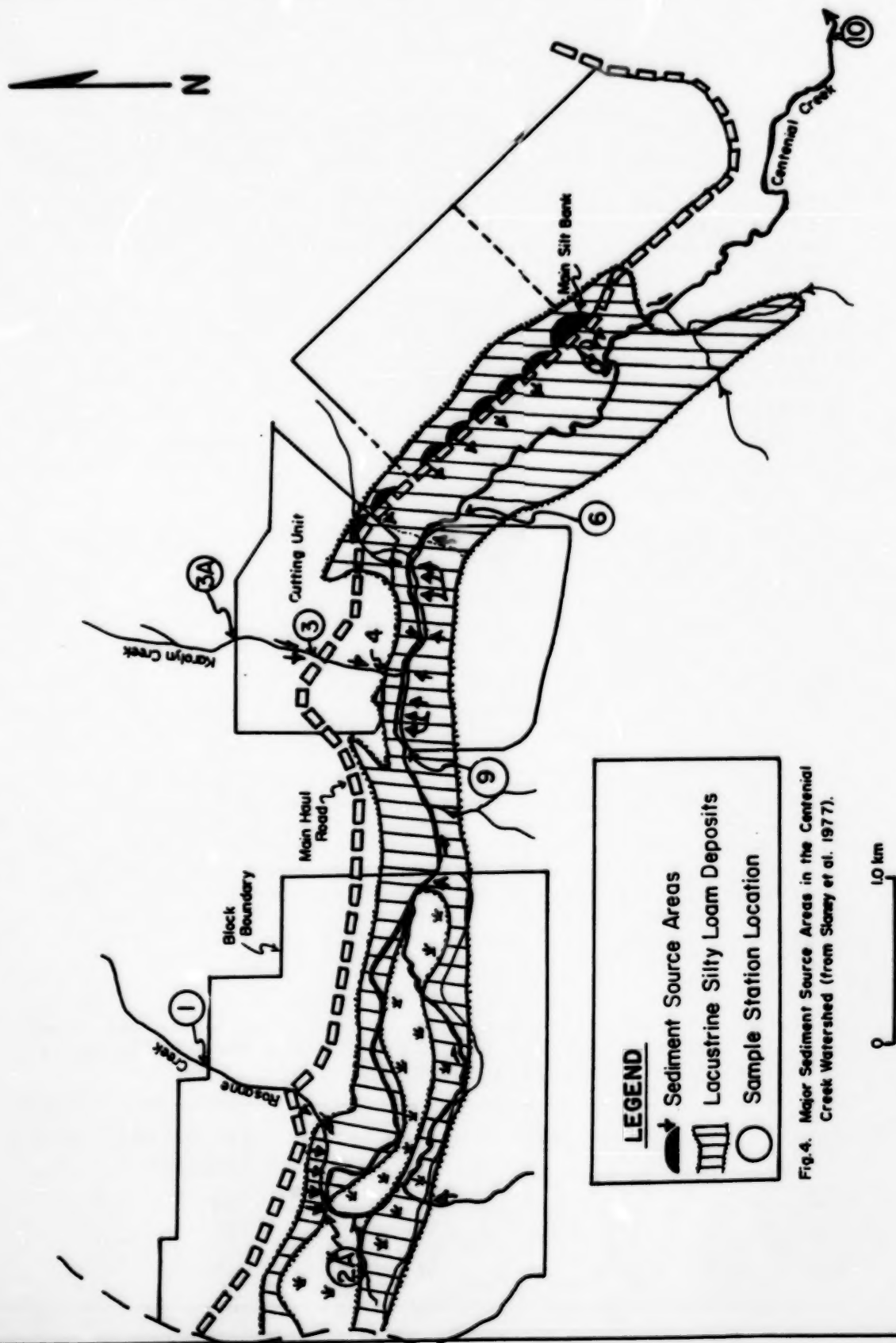


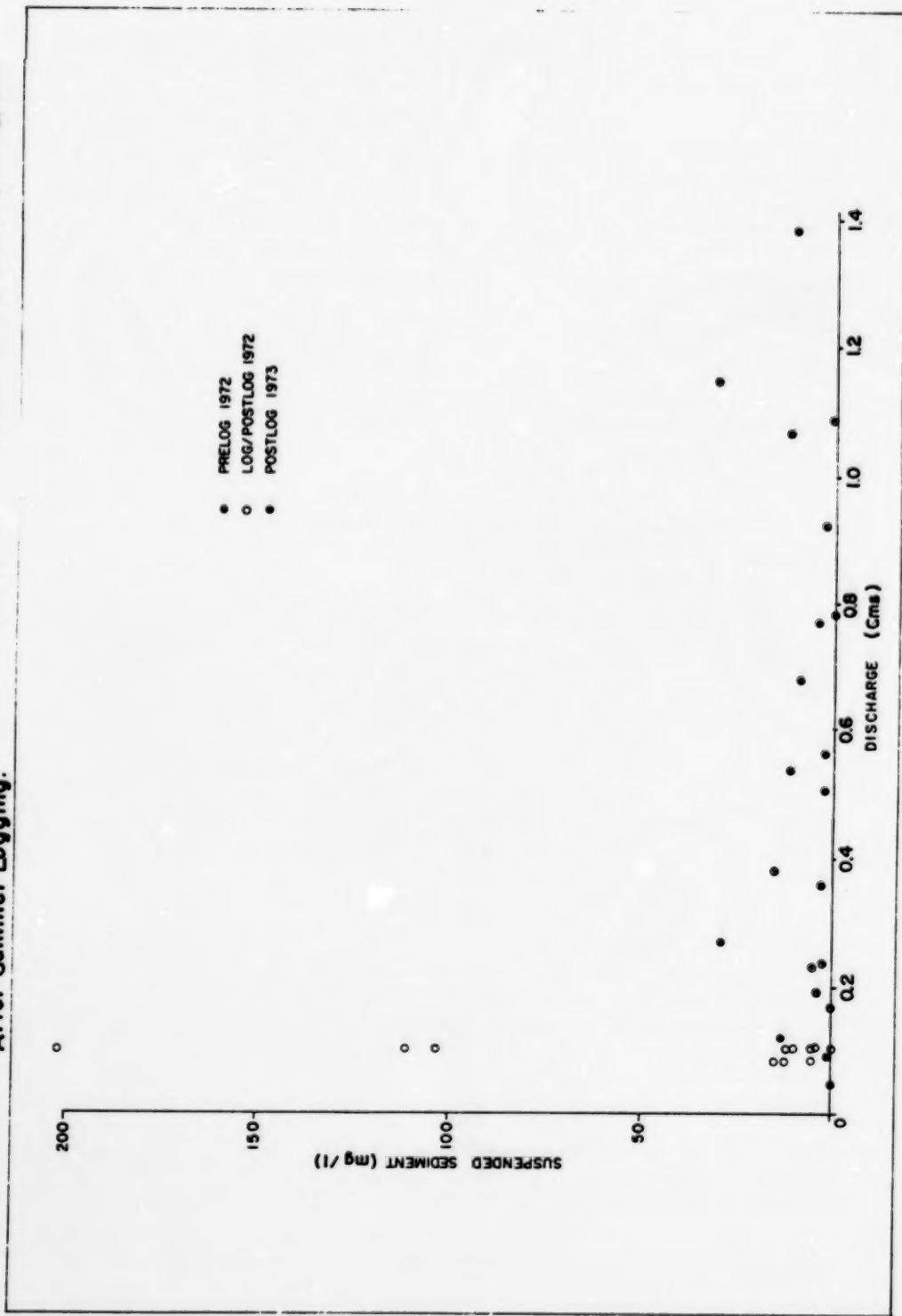
Fig. 4. Major Sediment Source Areas in the Centennial Creek Watershed (from Slaney et al. 1977).

The results of measurement of suspended sediment at different treatment sites in Rosanne and Karolyn creeks are shown in Table 5. Suspended sediment levels in the summer logged sites increased during the summer of logging (1972) in both Rosanne and Karolyn creeks. Mean levels during the post-melt period rose from control levels of 4 mg/l to a mean of 28 mg/l and a maximum of just over 200 mg/l. Sediment concentrations in logged areas dropped during periods of very low flow with no rain but rose following rains even when flow remained low. Figure 5 shows the sediment concentration versus discharge for Station 2 (below the summer logged area on Rosanne Creek), and indicates the range of values before and after logging. High values were invariably associated with specific activities, usually active skidding or rainstorms. Rosanne and Karolyn creeks had stabilized by the following summer, with comparable suspended sediment levels in both the control and logged sections.

Table 5. Mean and Maximum Suspended Sediment Concentrations (mg/l) at Sites Downstream of Logging Activities in Karolyn and Rosanne Creeks

Treatment	Stn	Mean (Maximum) Suspended Sediment				
		1972		1973		1974
		Melt	Post	Melt	Post	Melt
<u>Rosanne:</u>						
Control	1	23(26)	3(13)	6(84)	3(25)	9(27)
Summer Logged	2	10(31)	18(204)	10(194)	5(126)	11(56)
Winter Logged	2A	49(130)	57(136)	9(88)	3(42)	7(30)
<u>Karolyn:</u>						
Control	3A	29(73)	4(15)	5(37)	2(12)	8(54)
Summer Logged	3	29(47)	37(220)	6(57)	2(14)	7(29)
Winter Logged	4	36(108)	19(116)	7(79)	3(16)	7(18)
<u>Mean:</u>						
Control	1&3A	26(50)	4(14)	6(60)	2(18)	8(40)
Summer Logged	2&3	20(39)	28(212)	8(126)	4(70)	9(42)
Winter Logged	2A&4	42(119)	38(126)	8(84)	3(29)	7(24)

FIGURE 5. Sediment Discharge Relationship in Rosanne Creek (Station 2) Before, During, and After Summer Logging.



No differences in suspended sediment levels were measured at sites located in Hee Creek (Figure 1) upstream and downstream of summer logging (non-directional falling and skidding on low to moderate slopes). Suspended sediment levels averaged 10-20 mg/l with maximum levels of 60 mg/l during the snowmelt and summer period of 1973. Similarly, no differences in suspended sediment concentrations were noted in Leaner Creek (summer logged with directional falling and skidding on flat terrain; selective reserve strip in the lower end of setting). The average suspended sediment levels in Leaner Creek above and below logging were 2 mg/l with maximums of 8 mg/l.

In the winter logged sites on Rosanne and Karolyn creeks (1971-72), suspended sediment levels rose during the spring and summer after logging (1972) from 26 mg/l to 42 mg/l during the melt period and from 4 mg/l to 38 mg/l during the summer period (Table 5). There was very little difference between winter logged sites and the control sites in the following years. The measurements of the winter logging effects on sediment production are confounded by the summer logging upstream - and the results really represent a combination of summer and winter logging effects.

Some short-term monitoring of suspended sediment levels downstream of specific instream activities was conducted during the studies. For example, a culvert installation at Leaner Creek was monitored in June 1973. A bulldozer cleared snags, pushed out a flat base for the culvert, positioned the culvert, and filled the channel in about one hour. Sediment levels rose from 9 mg/l prior to disturbance to 15,158 mg/l during the installation. Suspended sediment levels dropped to 956 mg/l 5 minutes after the installation and to less than 100 mg/l one hour later.

A second example of short-term instream disturbance was monitored at this same crossing site. Five road construction machines forded this crossing twice daily for two weeks. Suspended sediment levels of 396 mg/l were measured at a monitoring site 0.5 km downstream one hour after the crossings.

No changes in suspended sediment levels were noted after slashburning at Rosanne Creek (Stations 2 and 2A), or after scarification adjacent Karolyn Creek (Stations 3 and 4). A strip on both sides of Rosanne Creek was not burned.

The diurnal variation of suspended sediment levels was examined in Centennial and Donna creeks during the spring of 1974. Sampling at different periods during the day indicated that there was a wide variation in suspended sediment levels depending upon when the sample was taken. For example, at Station 10 (Centennial Creek), suspended sediment levels on May 21-22 ranged from 27 mg/l to 175 mg/l. The lowest levels occurred at mid-day and the highest levels occurred near midnight. At Station 12 (Donna Creek), suspended sediment

levels ranged from 1 mg/l in the late afternoon (1600 hr) to 16 mg/l in the early morning period (0500 hr) of May 14-15. This diurnal variation of suspended sediment was not correlated to streamflows during this period.

WATER TEMPERATURE

Water temperatures increased during the summer in Hee, Karolyn, and Rosanne creeks (Figure 6). Maximum increases were 9 C, 4.5 C and 6 C respectively over upstream control levels. The maximum temperature reached was 19 C and occurred in Hee Creek during a low flow period in August 1972 (Table 6). Maximum temperatures in Karolyn and Rosanne creeks were 12 C and 17 C respectively. Temperatures in upper Slim Creek (Station 11) reached 21 C, and reflect the warming influence of Shandy Lake. The maximum temperatures recorded in Centennial and Donna creeks were a cool 14 and 12 C respectively.

Table 6. Maximum Water Temperatures (C) Recorded at Six Stations During 1973.

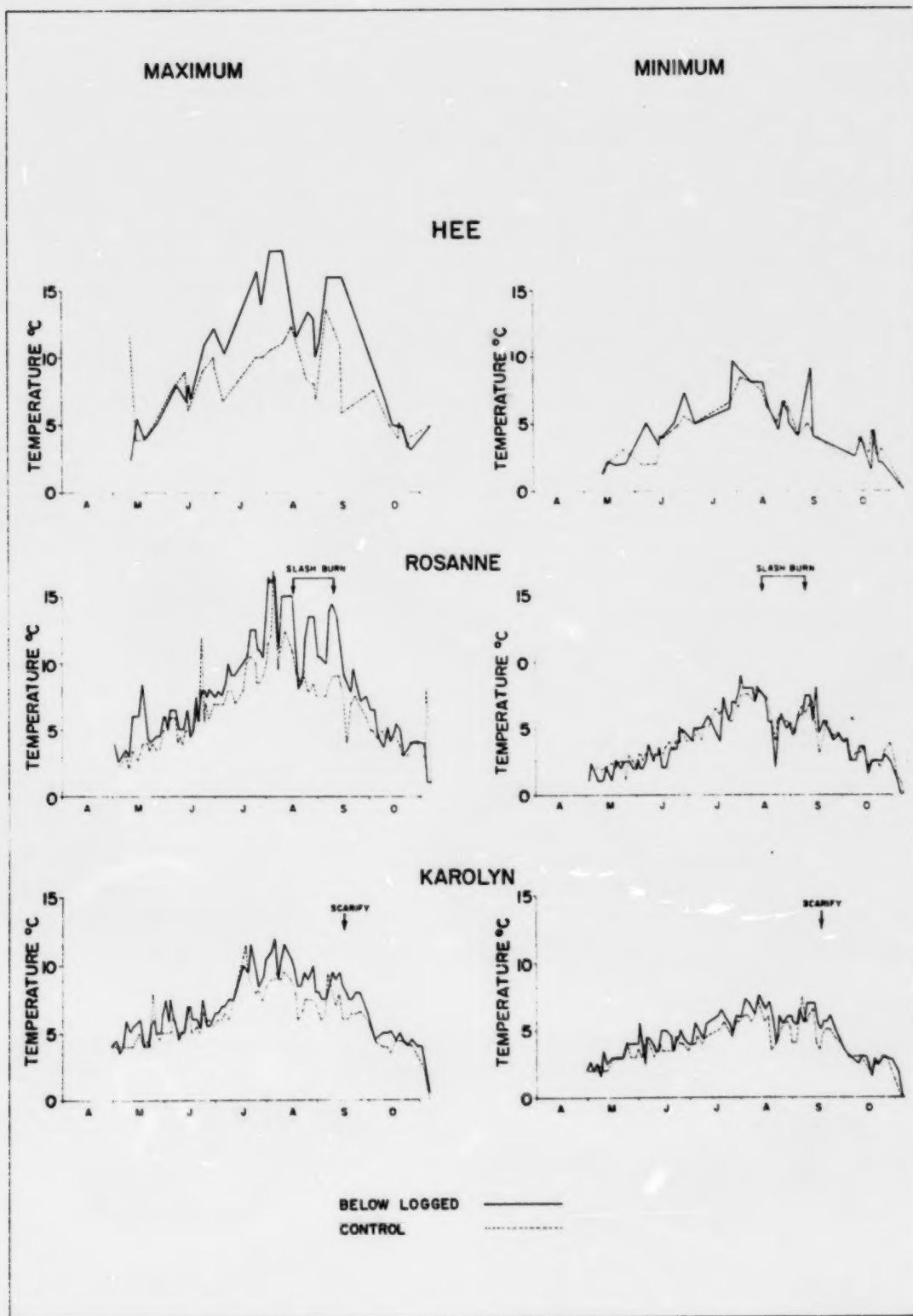
<u>Creek</u>	<u>Station</u>	<u>Max. Temp</u>	<u>Date</u>	<u>Comments</u>
Hee	LH	19	Aug 2&9	1600 m opening
Rosanne	2A	17	Jul 31	1170 m opening
			Aug 4	
Karolyn	4	12	Aug 4	970 m opening
Centennial	10	14	Aug 26	Leave strip
Slim	11	21	Aug 2	Control - lake-headed
Donna	12	12	Aug 9	Control - no lake

Maximum temperatures downstream of logged areas increased an average of 1 to 3 C in Hee, Rosanne and Karolyn creeks during 1973 (Table 7). These higher temperatures persisted throughout most of the period from late June to late September (Figure 6). Minimum temperatures were higher in Hee and Karolyn creeks and slightly lower in Rosanne.

Table 7. Changes in Maximum and Minimum Temperatures (C) Below Logging in Hee, Rosanne and Karolyn Creeks Compared to Upstream Unlogged Sites.

<u>Creek</u>	<u>Date</u>	<u>Average Max</u>	<u>Difference Min</u>
Hee	Aug 16-Oct 18	2.8	1.1
Rosanne	May 7-Nov 11	1.8	-0.1
Karolyn	May 7-Nov 11	1.0	0.7

FIGURE 6. 1973 Maximum and Minimum Water Temperatures at Hee, Rosanne and Karolyn Creeks, 1973.



Typical late summer diurnal water temperature fluctuations upstream and downstream of logging in Rosanne Creek are presented in Figure 7a. Water temperatures downstream of logging fluctuated over 8 C during a 24-hour period compared to fluctuations of 2 C in the upstream control site. A similar trend was noted in Leaner Creek where daily water temperature fluctuations of up to 11 C occurred in sites downstream of logging. Diurnal temperature changes at an upstream control site were one-half of those measured in the downstream site.

Subgravel water temperatures were typically 1-3 C lower than surface temperatures during the mid-summer period (Figure 7b). Increased fluctuation in surface water temperatures following logging was reflected in a similar pattern within the subgravel environment.

Maximum and minimum winter temperatures were 1-2 C lower downstream of logging on Rosanne Creek during the early winter of 1973. However, monitoring was incomplete due to equipment failure.

DISSOLVED OXYGEN

Dissolved oxygen levels never fell below 85% saturation (9 ppm at 10 C) at any stream sites downstream of logged areas. Annual and daily fluctuations reflected temperature variations in the streams. For example, lower dissolved oxygen levels downstream of logging in Hee Creek (10 ppm in control versus 8.6 ppm below logging) reflected higher water temperatures at the downstream site (17 C below logging versus 10 C in the control).

Subgravel dissolved oxygen samples taken in the summer of 1972 before and after logging on Rosanne Creek showed a slight decline following logging (Table 8). In 1973, subgravel oxygen levels fell below 5 ppm at only one location - the upstream control section of Hee Creek. No trend attributable to logging was noted.

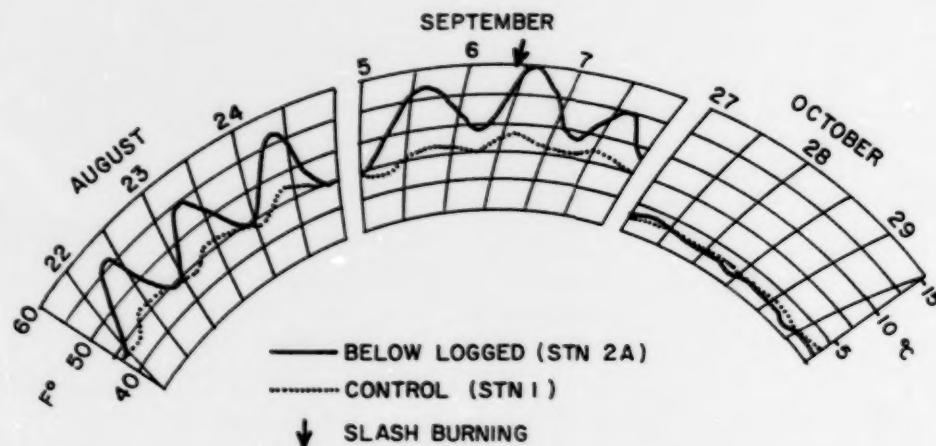
Table 8. Subgravel Dissolved Oxygen Levels in Rosanne Creek Above and Below Logged Areas During the Summer 1972.

<u>Station</u>	<u>Pre-logging</u>		<u>Post-logging</u>	
	<u>ppm</u>	<u>% sat*</u>	<u>ppm</u>	<u>% sat</u>
1 (Above logging)	10.0	68	8.7	64
2 (Below summer logging)	10.1	68	8.8	65
2A (Below winter logging)	6.8	47	4.9	38

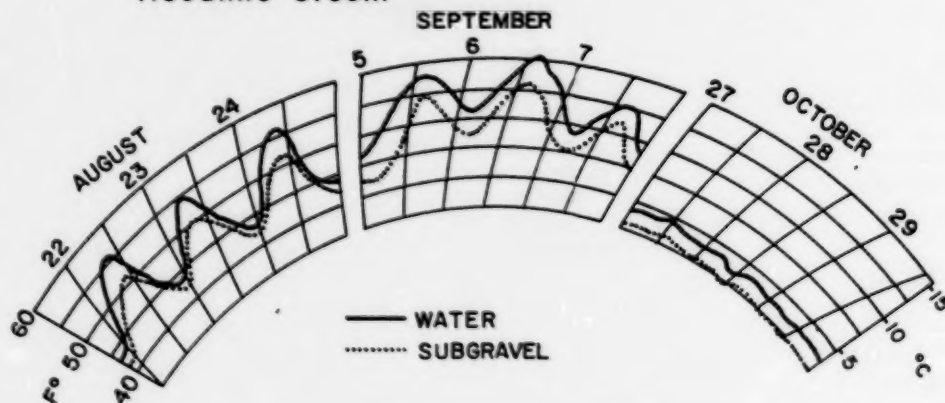
* Values are corrected for altitude and water temperature.

FIGURE 7.

A. Examples of Diurnal Fluctuation in Stream Water Temperatures Upstream and Downstream of Clearcuts on Rosanne Creek.



B. Examples of Difference Between Surface and Subgravel Water Temperatures at Station 2A, Rosanne Creek.



STREAM NUTRIENTS

Total Dissolved Solids

TDS levels in the logged (Centennial Creek at Station 10) and unlogged watershed (Donna Creek at Station 12) ranged from 60 to 150 mg/l throughout the measurement period (Figure 8). Highest levels occurred during the low-flow April period with a slight depression during the freshet period. TDS levels were similar in the logged and unlogged watershed.

No distinct changes were noted at stations located upstream in Centennial Creek compared to downstream locations (Figure 9) or at locations in Rosanne Creek above and below summer and winter logged sites (Figure 10). Rosanne Creek TDS levels dropped to as low as 23 mg/l during the high flow period in 1974. Changes in TDS levels were not detected following slashburning or scarification (Figures 10 and 11).

Individual Dissolved Constituents

Sodium, calcium, potassium, and manganese cation levels were examined above (Station 1) and below (Station 2) summer logging in Rosanne Creek during 1972. The results suggest that there is no detectable difference in cation levels between the logged and upstream control site (Table 9).

Table 9. Cation Levels (mg/l) in Rosanne Creek Above (Station 1) and Below (Station 2) Summer Logging from July 23 to September 21, 1972.

<u>Cation</u>	<u>Below Logging</u>		<u>Above Logging</u>	
	<u>Mean</u>	<u>Range</u>	<u>Mean</u>	<u>Range</u>
Na	0.9	0.7-1.1	1.1	0.9-1.4
Mg	1.0	0.8-1.2	1.0	0.9-1.1
Ca	11.1	10.0-11.9	11.7	11.0-12.7
K	0.2	0.1-0.3	0.3	0.1-0.5
Mn	Not Detectable			

A comparison of nutrient levels in the logged watershed (Station 10 on lower Centennial Creek) versus the unlogged watershed (Station 12 on lower Donna Creek) indicates that orthophosphate levels were similar (Table 10 and Figure 8). Total phosphate levels were not significantly greater in 1972, but increased slightly in 1973 and 1974, particularly during the spring and fall high flow periods.

FIGURE 8. TDS and Nutrient Concentrations at Stations 10 (logged) and 12 (control), 1972-1974

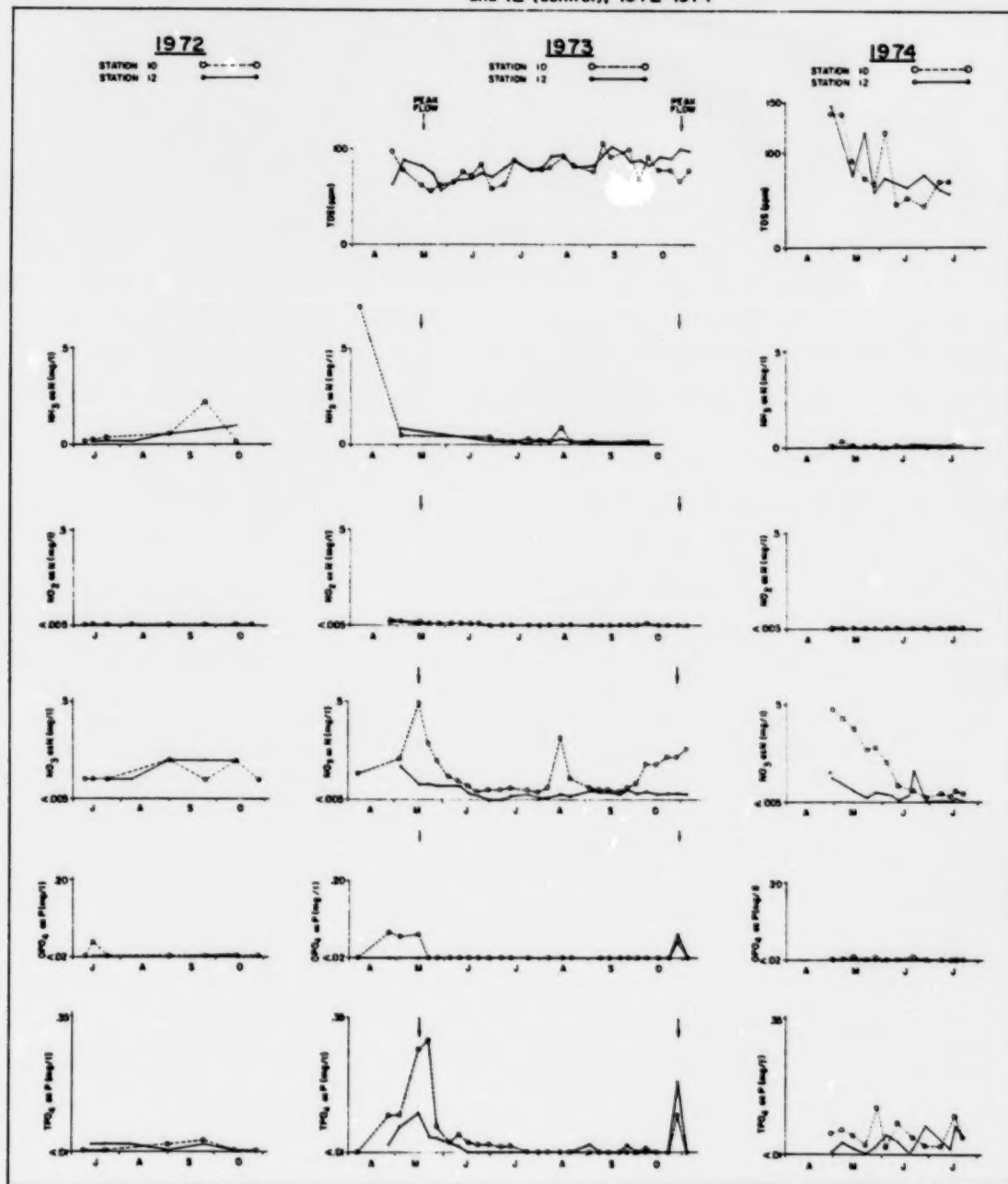


FIGURE 9. TDS and Nutrient Concentrations at Centennial Stations 6, 9, and 10 - 1973 and 1974

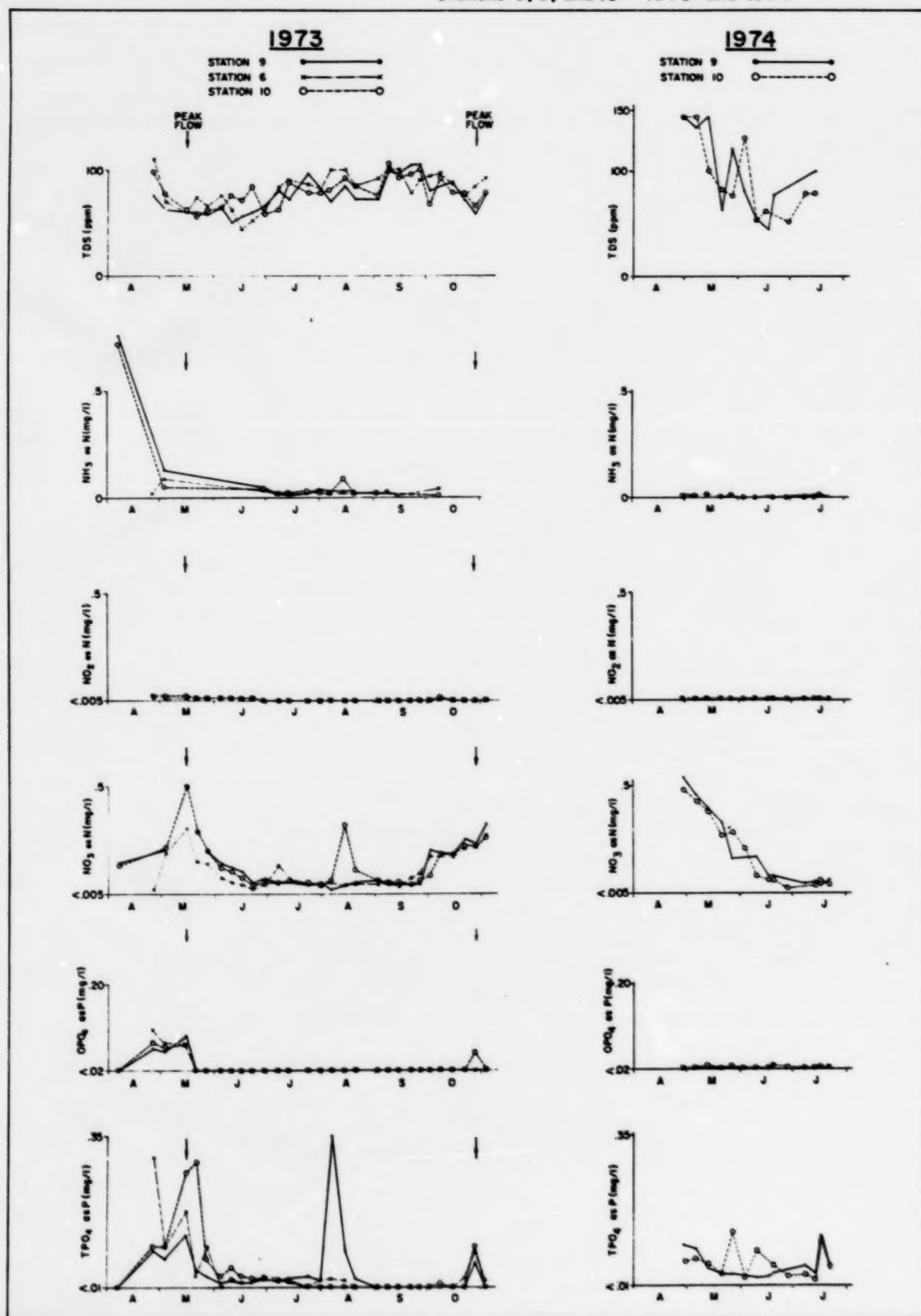


FIGURE 10. TDS and Nutrient Concentrations at Stations 1 (control), 2 (summer logged and burned), and 2a (winter logged)- Rosanne Creek, 1972 - 1974

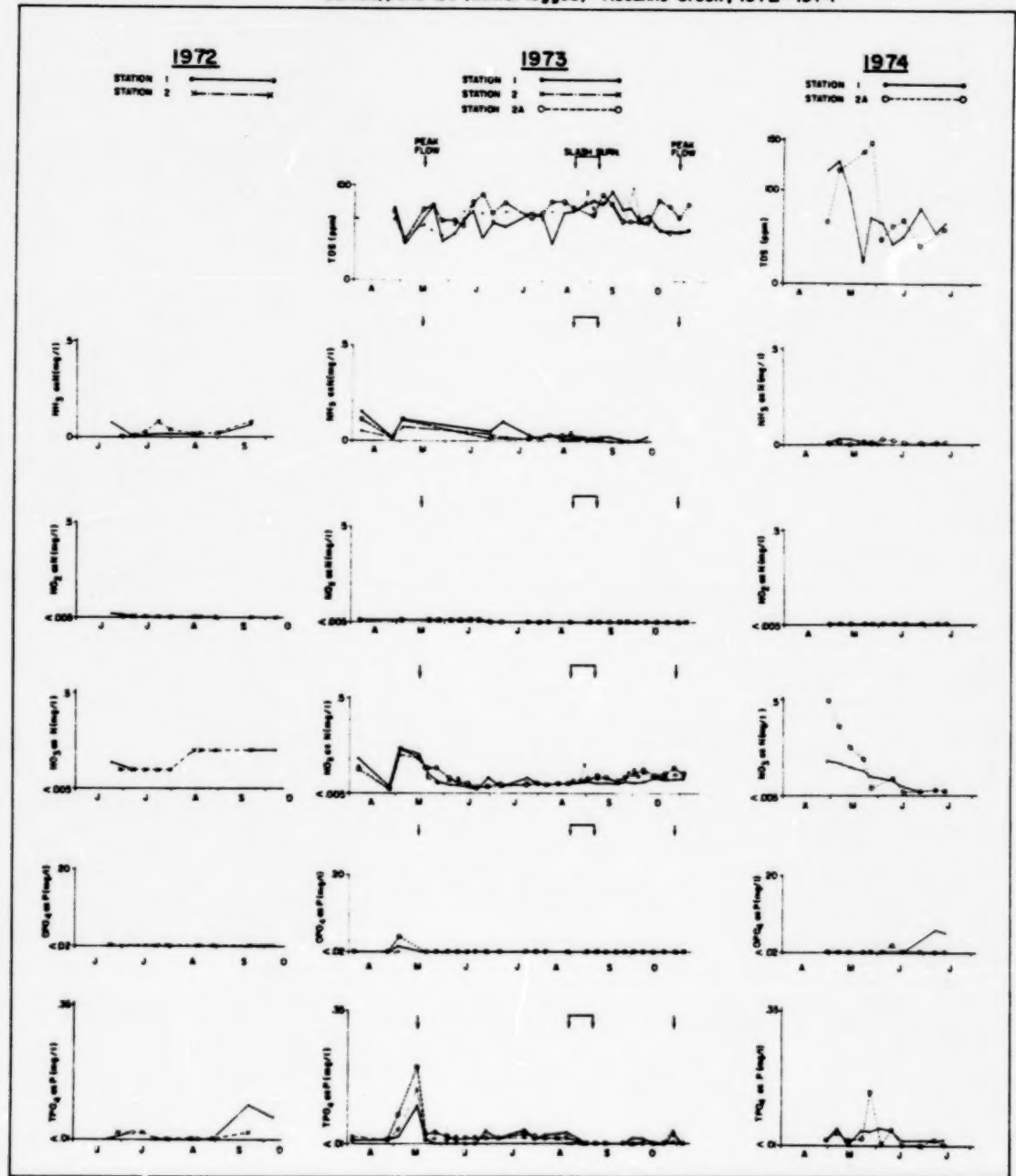


FIGURE 11. TDS and Nutrient Concentrations at Stations 3a (control) and 4 (logged and scarified) - Karolyn Creek, 1973 and 1974

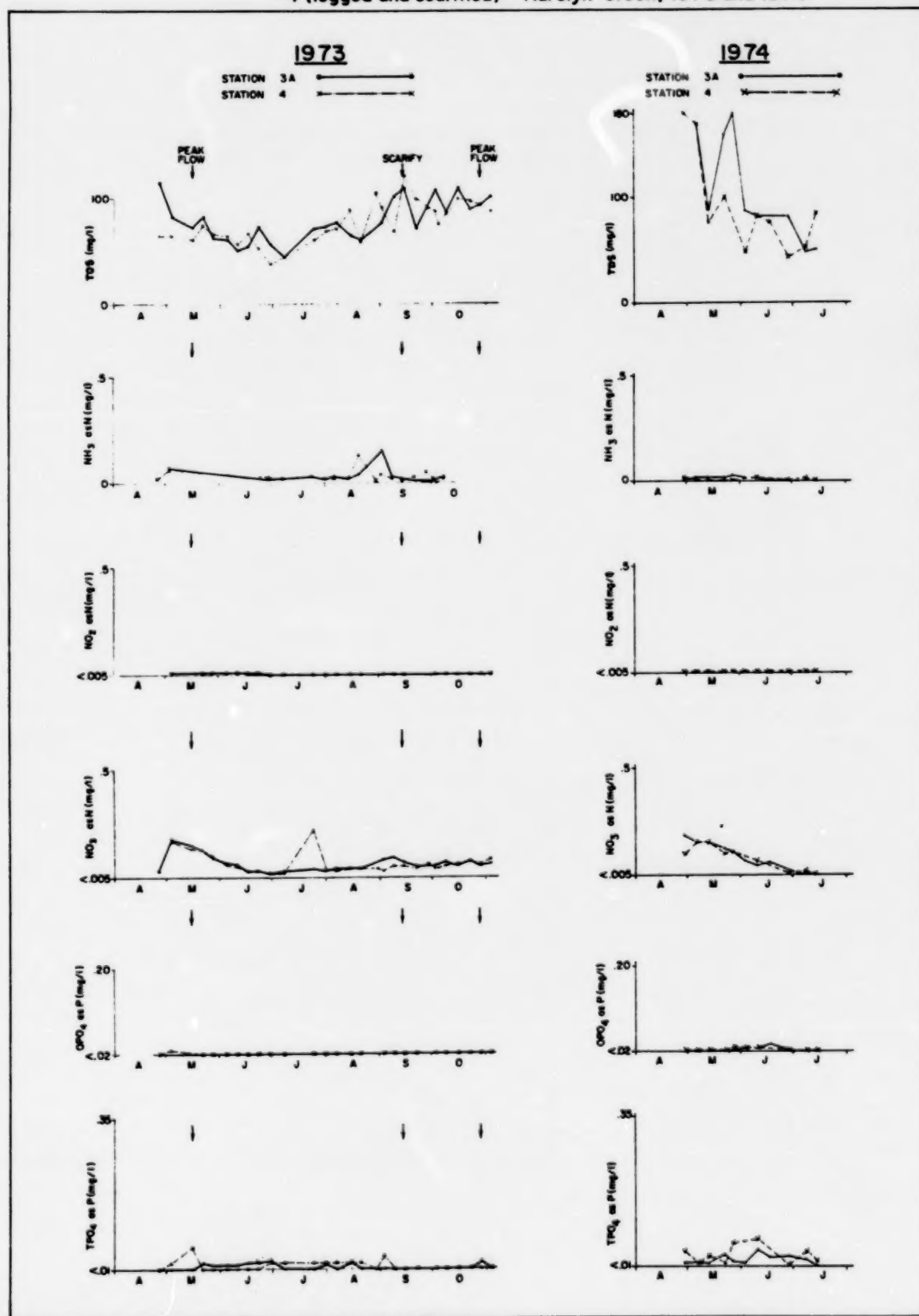


Table 10. Nutrient Concentrations (mg/l) in the Logged Watershed (Centennial Creek at Station 10) Versus the Unlogged Watershed (Donna Creek at Station 12).

Nutrient	Stn	Average (Maximum)		
		1972 (N=10)	1973 (N=57)	1974 (N=20)
Ortho PO ₄	10	<.01 (<.01)	<.002 (.020)	.007 (.020)
	12	<.01 (<.01)	<.002 (.006)	.006 (.014)
Total PO ₄	10	.010 (.030)	.027 (.290)	.050 (0.210)
	12	<.010 (.020)	.025 (.180)	.026 (.073)
NO ₂ as N	10	<.005 (<.005)	<.005 (.010)	<.005 (.006)
	12	<.005 (<.005)	<.005 (.015)	<.005 (.009)
NO ₃ as N	10	<.40 (<.40)	.22 (1.00)	.38 (.86)
	12	<.40 (<.40)	.08 (0.34)	.10 (.40)
NH ₃ as N	10	.083 (.230)	.068 (.720)	.012 (.030)
	12	.063 (.100)	.026 (.090)	.010 (.020)

Nitrate levels in the logged watershed were noticeably higher than in the unlogged watershed in 1973 and 1974 (Table 10), but were little different in 1972. Ammonia levels in the logged watershed were slightly higher in 1972 but were more than double the unlogged watershed levels in 1973. Ammonia levels declined to similar levels in both watersheds in 1974. Nitrite levels were usually below the detection limits in the two watersheds.

The seasonal cycle of orthophosphate, total phosphate, and nitrate concentrations peaked during spring break-up, with secondary peaks coincidental with heavy rains during summer and fall periods (Figures 8 and 9). When instream nutrient concentrations were at high levels (high flow periods), logged areas had 1-2 times the orthophosphate concentrations, 2-3 times total phosphate concentrations, and up to 5 times the nitrate concentrations present in the unlogged watershed (Table 11 and Figure 8).

No changes were noted in any of the monitored constituents following slashburning or scarifying in 1973 (Figures 10 and 11). Phosphates and nitrates increased slightly downstream of the burned area on Rosanne Creek, but no change was noted immediately downstream of the scarified area on Karolyn Creek (Table 12).

Table 11. Average Monthly Concentrations of Total Phosphorous and Nitrate (mg/l) at Stations 10 (Centennial Creek), Station 12 (Donna Creek), and Station 13 (Slim Creek at Tumuch Lake Inlet).

Station	Total Phosphorous			Nitrate		
	10	12	13	10	12	13
1973 May	.17	.06	.04	.30	.10	.13
Jun	.03	.04	.03	.08	.03	.07
Jul	<.01	<.01	<.01	.05	.02	.05
Aug	<.01	<.01	<.01	.16	.02	.05
Sep	<.01	<.01	<.01	.05	.04	.04
Oct	<.01	<.01	<.01	.18	.05	.09
1974 Apr	.06	<.01		.48	.12	
May	.06	.02	.03	.36	.06	.18
Jun	.04	.03	.03	.06	.04	.06
Jul	.04	.03		.03	<.01	

Table 12. Nutrient Concentrations (mg/l) Above and Below a Slashburned Site on Rosanne Creek and Above and Below a Scarified Site on Karolyn Creek.

Nutrient	Average (Maximum)		Average (Maximum)	
	Slashburn Above	Below	Scarified Above	Below
Ortho PO ₄	<.005	.009 (.042)	<.005 (.014)	<.005 (.010)
Total PO ₄	.027 (.049)	.044 (.230)	.028 (.106)	.029 (.064)
NO ₃ as N	.107 (.238)	.131 (.460)	.093 (.212)	.085 (.158)
NH ₃ as N	.014 (.030)	.010 (.018)	.012 (.022)	.013 (.020)
Sample Size	11	10	11	9

DISCUSSION

SUSPENDED SEDIMENT

Suspended sediment loading in lower Centennial Creek (logged) increased 4 to 12 times over corresponding levels in lower Donna Creek (unlogged watershed) depending upon the year of measurement. The high sediment loading persisted for the duration of the 3 years of study (Table 2). In Centennial Creek, measured suspended sediment levels rarely exceeded 500 mg/l but averaged between 70-90 mg/l for the April through June period (Table 3). The levels were reduced to near 30 mg/l during the summer/fall period with the highest levels during this period coinciding with fall rains.

These chronically high suspended levels occurred despite Centennial Creek being largely isolated from falling, skidding and road building operations by reserve strips. The sediment sources were largely related to the mainline road development in the Centennial watershed, especially in the section of road traversing silty loam soils (Figure 4). Erosion from skid trails, landings, road crossings, and streambank damage in upstream tributaries also contributed to the higher suspended sediment levels in Centennial Creek. However, increased sediment levels in the summer and winter logged sites in Rosanne and Karolyn Creek did not persist beyond the first summer after logging, reflecting the coarse textured soils occurring in these tributary watersheds.

Results from the suspended sediment sampling indicated that considerable variation in suspended sediment levels could occur in a stream without significant flow changes on a single day during the snowmelt period. These results suggest that the timing of sampling in these types of watersheds can have a significant effect on determining accurate sediment loadings, and is an important consideration when designing suspended sediment monitoring studies in interior watersheds.

Increased suspended sediment levels related to logging activities have been found in studies conducted elsewhere prior to the work in Centennial Creek. For example, Brown and Krygier (1971) found that road construction, clearcutting and subsequent slashburning resulted in an average four-fold increase in suspended sediment levels in a study stream that took four years to recover to pre-logging levels. Hornbeck and Reinhart (1964) measured increased maximum suspended sediment levels up to 450 times pre-logging levels following skidder logging without skidtail layout. Other studies such as Copeland (1962), Fredrickson (1970), Rice and Wallis (1962), and Burns (1970) have all measured increased suspended sediment levels in streams downstream of logging.

Results of gravel sampling at simulated redd sites in lower Centennial Creek in 1974 indicated that the mean percentage of sediment increased significantly from mid-spring to mid-summer; fines <1.19 mm increased by 68%, fines <0.297 mm increased by 123%, and fines <0.074 increased by 107% (Slaney et al. 1977a). Porosity of gravel sites in Centennial Creek significantly decreased over the three-month study period. Deposition of sediment in the finer categories was greatest in stream reaches with the highest suspended sediment duration and was greatest in the upper layers of the gravel which became encrusted with fine sediments at some sites.

Experimental channel data on fry survival to emergence in conjunction with the results of the gravel sampling suggests that average survival to emergence of trout fry in 1974 would have been reduced by approximately 30%. Percent fines and potential egg-to-fry mortality was probably greater in 1973 based on similar sediment concentrations but lower discharges during the summer of 1973.

Suspended sediment concentrations usually did not reach levels that could cause direct mortality by gill abrasion to rearing fish. Concentrations in the study streams did not exceed 200 mg/l for extended periods of time during the study. Herbert and Merkin (1961) demonstrated that gill damage and increased mortality in rainbow trout bioassays occurred at concentrations of 270 to 810 mg/l for 10 days. Short-term exposure to concentrations of about 20,000 mg/l can be lethal (Langer 1974). Short duration sediment releases at specific roadway activities such as the culvert installation on Leaner Creek approached these levels.

However, increased suspended sediment levels in the logged study streams affected juvenile fish rearing habitat by reducing benthic food organisms and available winter habitat (Slaney et al. 1977b). Density and biomass of benthic invertebrates in 1973 prior to the spring melt were similar in Centennial and Donna creeks. In July, after spring melt, density and biomass of benthic organisms in Centennial Creek were one-third those in Donna Creek. The abundance of insect drift in lower Rosanne Creek was much lower than the upstream site, but the direct cause of this reduction is not clear and cannot be attributed to sediment levels in this tributary.

Rubble areas in runs and pools in lower Centennial Creek during July 1973 had substantial amounts of sediments deposited in at least 50% of the area surveyed (Slaney et al. 1977b). This reduced available habitat for salmonids that move into rock interstices during the winter period.

Sediment inputs from the logging in Centennial Creek

resulted in a marked decrease in the water transparency in Tumuch Lake (Parkinson et al. 1977). Most of the suspended sediment entering Tumuch Lake settled out in the southern half of the Tumuch inlet basin, but fine suspended particles reduced water transparency during spring to early summer, particularly in the inlet basin. As deformation of the Tumuch Lake watershed increased from 1.6% in 1972 to 7.3% in 1974, Secchi disc readings in the inlet basin were reduced by greater than 50% during May and June in 1974 and 1975. This resulted in reduced phytoplankton production in the lake. No differences to fish growth rates or relative abundance within the lake could be attributed to changes before and after logging in the upstream watershed.

WATER TEMPERATURE

Water temperatures increased an average of 1 to 3 C in the logged streams during the study period (Table 7). As well, diurnal fluctuations in water temperature more than doubled in the study streams (Figure 7a) and summer maximums increased between 4 and 8 C. However, water temperatures did not exceed 19 C at any of the stations downstream of the logged areas (Table 6), and remained at tolerable, and in some instances, cool levels for salmonids throughout the study period. For example, water temperatures in Karolyn Creek did not exceed 12 C despite clearcutting to the edge of this stream. The highest temperatures recorded during the study (21 C) were in upper Slim Creek downstream of Shandy Lake where no logging had taken place.

The trend for increased water temperatures downstream of clearcutting is in general agreement with other studies (Gibbons and Salo 1973). Studies of water temperature changes conducted elsewhere have indicated average increases in summer water temperatures ranging from 6 C on Vancouver Island (Narver 1972) to 14 C in the Oregon Coast Range (Brown and Krygier 1970).

Higher water temperatures in the clearcut areas was considered the main cause of increased fish growth rates in the study streams (Slaney et al. 1977b). Juvenile rainbow trout growth rates were greater in the logged sections of the streams than in the upstream control areas. Fry growth rates were up to 100% greater in the summer logged area than in the control in August of 1973. Yearlings were also between 65 and 166% larger by fall in the downstream clearcut areas compared to control stations. Increased fish growth rates recorded in this study suggest higher water temperatures following clearcutting would be beneficial to fish in cool streams like Karolyn and Rosanne creeks. However, such increases would probably be unfavourable in small lake outlet streams such as upper Slim Creek where late summer water temperatures already nearly exceed tolerance levels.

for salmonids. For example, Tyler et al. (1973) found water temperatures approached lethal levels in logged lake outlet streams in Alaska.

Subgravel water temperatures, although cooler than surface water, tended to respond in a similar pattern to clearcutting as the surface waters (Figure 7b). Although not measured, it is assumed that warmer incubation temperatures during the summer period would result in more rapid trout egg and alevin development, possibly leading to earlier emergence of fry downstream of logged sites. This could be favourable, as these fish would achieve a larger size prior to their first winter, probably resulting in better overwinter survival.

Despite incomplete monitoring, results suggest maximum and minimum water temperatures were 1 to 3 C lower downstream of the clearcuts on Rosanne Creek in the early winter of 1973. Results from other studies are inconclusive concerning the effects of clearcutting on stream winter temperatures. For example, Eschner and Larmoyeux (1963) found winter temperatures in West Virginia to be 3.5 C lower in the clearcut stream, but Meehan et al. (1969) found little change in southeast Alaska streams.

STREAM NUTRIENTS

Total dissolved solids levels (60-150 mg/l) in the study streams did not change with logging or slashburning in either 1973 or 1974. These levels were typical of levels (49-210 mg/l) reported for the Northern Interior Plateau (Northcote and Larkin 1956). Fredriksen (1971) found TDS levels in an Oregon Cascade stream increased after logging and again after slashburning to a peak of 55 mg/l, then to fall slowly over a six-year period to the former level of 40 mg/l.

Cation levels in the study streams were low and did not increase following logging (Table 9). Other studies (Brown 1974) have shown a 2 to 15-fold increase in Na, K, Ca, and Mg following logging.

Considerable emphasis was placed on the measurement of changes in nitrogen and phosphorous levels in the study streams following logging. These two nutrients typically limit primary production in streams and lakes (Vollenweider 1974). When instream nutrient concentrations were at high levels, logged areas had 1-2 times the orthophosphate concentrations, 2-3 times total phosphate concentrations, and up to 5 times the nitrate concentrations present in the unlogged watershed. However, the nutrient concentrations in Tumuch Lake during the spring and summer were only slightly higher than the control levels reflecting the dilution by upper Slim and Donna creeks of the

higher nutrient concentrations in Centennial Creek (Parkinson et al. 1977). The small increases in nutrient concentrations at the inlet to Tumuch Lake were not surprising considering the small percentage of the watershed that was clearcut and burned.

Much larger increases in nitrate concentrations in streams have been reported in completely clearcut and burned watersheds (Pierce et al. 1972; Fredriksen 1971; Brown et al. 1973). As well, a smaller increase in total phosphorous concentration, compared to nitrate, is typical of the results reported elsewhere. No increase in total phosphorous concentrations were noted by either Brown et al. (1973) or Pierce et al. (1972) on completely clearcut and burned watersheds, and Fredriksen (1971) reported only small increases in total phosphorous on a watershed that was completely logged and burned.

MANAGEMENT IMPLICATIONS

The implications of this study's results to forest harvesting practices in the central interior of British Columbia have been discussed in detail in Slaney et al. (1977a - reprinted in Appendix 1) and to a lesser extent in Slaney et al. (1977b and 1977c) and Parkinson et al. (1977). Increased sediment, particularly from roads, and to a lesser extent harvesting operations, altered stream temperature regimes, and increased nutrient inputs to downstream locations were all documented in this study. As well, Slaney et al. (1977c) documented physical alterations to stream channels such as increased bank erosion, and more debris accumulations and channel diversions depending upon streamside logging procedures. Based on the results of these studies, the following management recommendations are made:

- 1.) Sources of sediment transported to Centennial Creek were primarily the main haul road and to a lesser extent skid trails, landings and stream channels. The use of detailed landform and soil mapping in watersheds of high fisheries value would help to identify potential high hazard areas. If the main haul road had been shifted to avoid the highly erodible soils encountered in the vicinity of Karolyn Creek, much of the erosion that occurred in this study could have been avoided.
- 2.) The subgrade was constructed during the winter period. This augmented sediment movement to the stream since snow was mixed with soil on the fill slopes causing road banks to slump and sediment transport, either in ditches or small channels or by overland flow. The reserve or filter strip was largely effective in intercepting overland flow of sediment after winter construction of the subgrade but was

not effective in preventing transport of sediment from ditches, culverts, and small drainage networks. Construction in sensitive areas should be timed to avoid wet periods or during the winter. Special measures to avoid erosion in ditches and from cut and fill slopes should be undertaken as described in Slaney et al. (1977a). In particular, culvert size and frequency must be adequate to handle streamflows in the area and maintained to ensure that blockage from debris does not lead to washouts.

3.) Roads, landings, and skid trails located in sensitive soil types and moderate to steep slopes contributed significant amounts of sediment to Centennial Creek. Techniques including minimizing and contouring secondary road grades, ensuring adequate cross-drains, re-vegetating erodible slopes, and removing winter bridges prior to spring melt will help minimize erosion. Landings should avoid natural water courses and avoid concentrating run-off. As well, skid trail layout should be pre-planned rather than left to the discretion of the contractor. This would help to avoid the use of the stream channels for skidding, and would minimize stream crossings and the amount of ground disturbance. The season of logging, adequately marking streams in winter-logged settings, and proper drainage control on skid trails are important considerations for interior logging operations.

4.) Determining the most appropriate streamside treatment will depend upon factors such as fisheries or wildlife values to be protected, terrain and landform, erosion and windthrow potential, vegetative cover, and timing of logging. Options such as directional falling and skidding, selective reserves, and total reserve strips are available and are discussed in more detail in Slaney et al. (1977c).

5.) In some central interior streams, warmer summer water temperatures resulting from the removal or partial removal of adjacent stream vegetation can provide benefits to fish growth. Mountain streams with naturally low temperature regimes are good candidates to benefit from warmer temperatures. Small lake-headed streams such as upper Slim Creek may already have high water temperatures and would not benefit from increased temperatures resulting from removal of streamside vegetation. As well, the implications of vegetation removal along small streams to winter temperature and ice conditions are not fully understood.

6.) Some benefits to stream and lake productivity may be derived from increased nitrogen and phosphorous levels following logging and silvicultural treatments such as slashburning. In this study, these effects on downstream areas were confounded by dilution from other tributaries and increased turbidity levels, and by the small proportion of the watershed logged.

7.) The observations suggesting changes in stream morphology noted during the 1987 field trip to the Slim Creek watershed (see Preface) should be confirmed by conducting a detailed comparison of stream morphology as measured in the mid-70's compared to the present. The results of such a study could provide valuable insights into the long-term implications of logging across small interior streams.

REFERENCES

- Brown, G.W. and J.T. Krygier. 1970. Effects of clearcutting on stream temperature. *Wat. Resour. Res.* 6(4):1133-1140.
- Brown, G.W. and J.T. Krygier. 1971. Clearcut logging and sediment production in the Oregon Coast Range. *Wat. Resour. Res.* 7(5):1189-1199.
- Burns, J.W. 1970. Spawning bed sedimentation studies in northern California streams. *Trans. Amer. Fish. Soc.* 101(1):1-17.
- Copeland, O.L. 1965. Land use and ecological factors in relation to sediment yields. In: Proceedings of Federal Interagency Sedimentation Conference, U.S. Dept. Agric. Misc. Publ. No. 970. p. 72-84.
- Fredriksen, R.L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. U.S.D.A. For. Serv., Pac. NW For. Range Expt. Sta. Res. Pap. PNW-104, Portland, Oregon.
- Fredriksen, R.L. 1971. Comparative chemical quality - natural and disturbed streams following logging and slashburning. In: J.T. Krygier and J.D. Hall (Eds.) Forest Land Uses and Stream Environment Symposium, Oregon State University. p. 125-137.
- Gibbons, D.R. and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. U.S.D.A. For. Serv., Pac. NW For. Range Expt. Sta. Gen. Tech. Rep. PNW-10, Portland, Oregon.
- Herbert, D.W.M. and J.C. Merckens. 1961. The effect of suspended solids on the survival of trout. *Internat. J. Air Wat. Poll.* 5:46-55.
- Hornbeck, J.W. and K.G. Reinhart. 1964. Water quality and soil erosion as affected by logging in steep terrain. *J. Soil. Wat. Conserv.* Jan/Feb:23-27.
- Langer, O.E. 1974. Effects of sedimentation on stream productivity. In: G.A. Drew (Ed.) Stream Ecology, FP-2407, Cent. Cont. Educ., Univ. of B.C., Vancouver, B.C.
- Eschner, A.R. and J. Larmoyeux. 1963. Logging and trout: Four experimental forest practices and their effect on water quality. *Prog. Fish-Cult.* April 1963.

- Meehan, W.R., W.A. Farr, D.M. Bishop, and J.H. Patric. 1969. Some effects of clearcutting on salmon habitat of two southeast Alaska streams. U.S.D.A. For. Serv., Pac. NW For. Range Expt. Sta. Res. Pap. PNW-82, Portland, Oregon.
- Narver, D.W. 1972. A survey of some possible effects of logging on two eastern Vancouver Island streams. Fish. Res. Bd. Canada Tech. Rep No. 323.
- Northcote, T.G. and P.A. Larkin. 1956. Indices of productivity in British Columbia lakes. J. Fish. Res. Bd. Canada 13(4):515-54-.
- Parkinson, E.A., P.A. Slaney, and T.G. Halsey. 1977. Some effects of forest harvesting on a central interior lake in British Columbia. B.C. Min. Environ., Fish and Wildl. Branch, Fish Manage. Rep. No. 17.
- Pierce, R.S., C.W. Martin, C.C. Reeves, G.F. Likens, and F.H. Bormann. 1972. Nutrient loss from clearcutting in New Hampshire. In: S.C. Csallany, T.G. MacLaughlin, and W.D. Striffler (Eds.) Proceedings of a Symposium on Watersheds in Transition, Colorado State Univ.
- Rice, R.M. and J.R. Wallis. 1962. How a logging operation can affect streamflow. For. Ind. 89(11):38-40.
- Slaney, P.A., T.G. Halsey, and A.F. Tautz. 1977a. Effects of forest harvesting on spawning habitat of stream salmonids in the Centennial Creek watershed British Columbia. B.C. Min. Environ., Fish and Wildl. Branch, Fish. Manage. Rep. No. 73.
- Slaney, P.A., T.G. Halsey, and H.A. Smith. 1977b. Some effects of forest harvesting on salmonid rearing habitat in two streams in the central interior of British Columbia. B.C. Min. Environ., Fish and Wildl. Branch, Fish. Manage. Rep. No. 71.
- Slaney, P.A., H.A. Smith, and T.G. Halsey. 1977c. Physical alterations to small stream channels associated with streamside logging practices in the central interior of British Columbia. B.C. Min. of Environ., Fish and Wildl. Branch, Fish Manage. Rep. No. 31.
- Taras, M.J., A.E. Greenburg, R.D. Hoak, and M.C. Rand. 1971. Standard Methods for the Examination of Water and Wastewater (13th ed). Amer. Publ. Health Assoc., Washington, D.C.
- Tyler, R.W., D.R. Gibbons, and E.O. Salo. 1973. Effects of logging on salmon-producing streams of southeast Alaska. In: 1972 Research in Fisheries, Cell. Fish., Univ. Washington, Seattle, p. 25-26.

Vollenweider, R.A. 1970. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorous as factors in eutrophication. OECD Committee on Research Cooperation, Paris, 159 pp.

APPENDIX 1

The following specific management recommendations concerning logging and road development in the vicinity of streams were developed based on the results of water quality and fisheries studies in the Slim Creek watershed. Since the report that the recommendations first appeared in (Slaney et al. 1977a) is no longer widely available to readers, these recommendations have been reprinted here.

MAIN HAUL ROADS

1. Location of Main Roads: Intensive use of landform inventory is required to select a main road location that minimizes both transport and overland flow of sediment to streams. At Centennial Creek avoidance of extremely erodible soils would have greatly reduced sediment movement to the stream. The subgrade, cut-slopes and fill slopes in the 2.8 km section of road east of Karolyn Creek were located in undulating and moderately sloping deposits of materials comprised of silt, fine sand and a small proportion of clay. During planning, if landform distribution was known, locating the road 0.2 to 0.5 km up-slope in loamy till and colluvial soils would have avoided highly erodible soils. Accordingly, the location of the upper 4 km of the road was within loamy till and colluvial materials on similar slopes and little erosion was evident.

The reserve or filter strip was largely effective in intercepting overland flow of sediment after winter construction of the subgrade and filtered out ca. 1600 m³ of sediment at the largest cut and fill slope (T.W. Chamberlin pers. comm. 1973). However, it was not effective in preventing transport of sediment from ditches, culverts and small drainage networks.

2. Construction of the Main Road: During construction in erodible materials, especially when associated with moderate to steep slopes, intensive application of several guidelines apply:

- a. Avoid winter construction except stable landforms with little snow.
- b. A much higher frequency of culverts is required in erodible soils.
- c. Culvert outfalls must have either rock and debris aprons or pipe extensions beyond the base of the slope.
- d. Disturbance of the surface must be minimized; limit the area of cut and fill slopes in unstable materials.

- e. Gravelly materials without fines should be used at culvert placements.
- f. Culvert size must be sufficient to prevent blockage and debris control devices installed to prevent washouts.

At Centennial Creek the construction of the main haul road east of Centennial Creek caused additional erosion from mixing soil and snow on fill slopes and probably increased moisture in the cut-slope and subgrade. Sediment transport was also high because culvert frequency was inadequate relative to the size of the cut and fill slopes and the materials. Culverts were positioned at main drainage courses which also collected sediment from ditches. Use of small culverts at frequent intervals between drainages would have diverted some of the transported sediment into the filter strip rather than into water courses. In preparation of the subgrade a larger width of the "duff" layer was frequently disturbed than necessary, particularly in flatter terrain. It was evident near Slim Creek that placement of the surface grade (gravelly soil) over the "duff" layer eliminated disturbance of the lacustrine deposits. Culvert washout occurred on at least two drainages on the 2.8 km section of road east of Karolyn Creek as a result of erosion at culvert outfalls and culvert blockage. Similarly, the culvert at a tributary of Leaner Creek diverted the stream along the road during a July (1974) rainstorm, causing a major sediment release into Leaner Creek. Culverts on Rosanne, Karolyn, and Leaner creeks, however, were large and operated throughout the study period without washout or blockage. During installation, however, culverts also produced more sediment transport than necessary; 15,160 mg/l during the duration of disturbance of erodible soils at Leaner Creek, but measurements were not made at Rosanne and Karolyn creeks.

3. Stabilization of the Main Haul Road:

- a. Place slash on fill slopes.
- b. Revegetate highly erodible slopes with grass and where necessary, restock with fast growing trees; this should be implemented as a necessary phase in the forest harvesting procedure.
- c. Inspect and clean out culvert entrances and ditches regularly.

Both clearing of ditches and culvert areas, and the use of slash were employed along the main road east of Karolyn Creek although additional slash would have assisted in reducing slumpage and overland flow of sediment from fill slopes. During

1974 the erodible slopes were also revegetated with grass by hand seeding and use of fertilizer. Seeding was effective over approximately 50% of the disturbed soil, but steeper areas did not revegetate. These would have required mulching and reseeding with an hydroseeder and stocking with trees.

CUTTING UNITS

Cutting units also contributed significant amounts of transported sediment to Centennial Creek from secondary roads, skidtrails and landings if associated with the same materials as discussed previously. In the upper valley, slopes were gentle in areas of lacustrine deposits and sediment sources were mainly winter bridges and the secondary road (T.W. Chamberlin pers. comm. 1973). However, at the south slope of Centennial Creek near Karolyn Creek, slopes were moderate to steep and produced sediment from secondary roads, skidtrails and landings associated with the same materials (lower third of the unit). Total sediment load in Centennial Creek in May to July doubled between the upstream and downstream margins of the unit. The 20 m reserve strip was not wide enough to prevent movement of sediment from skidtrails. The unit on the north side of the valley also caused transport of sediment from the same deposits but slopes were less and surface erosion was largely restricted to a secondary road at the eastern margin. Several recommended practices apply to these types of areas, other than placing them in reserve until development of new logging technology:

1. Secondary Roads

- a. Road grades should be as small as possible, contoured to slopes or placed on benches, and placement avoided in fine soil deposits.
- b. A high frequency of cross drains is necessary to disperse transported sediment into slash and dissipate runoff.
- c. Stabilize erodible slopes of roads by vegetation.
- d. Materials utilized for construction of approaches and the surface of winter bridges should be comprised of gravel.
- e. Winter bridges should be removed prior to spring melt if restriction of streamflow, including debris movement, is probable.

2. Landings in Cutting Units

- a. Avoid natural watercourses and seepage networks.
- b. Restrict landings to locations that minimize concentration of runoff from skidtrails.
- c. Spread fine landing slash as a mulch on disturbed soils to minimize erosion.
- d. Revegetate erodible sites with grass seed.

3. Skidtrails in Cutting Units

- a. Minimize the percentage of cutting unit utilized for skidding (i.e. maximize spacing).
- b. Plan skidtrail layout rather than permitting contractors to select skidding routes.
- c. Minimize skidtrail slopes, avoiding steeper grades by contouring to slopes.
- d. Restrict operations during spring melt and autumn freezing.
- e. Install a series of water bars to drain skidtrails and prevent erosion.
- f. Revegetate with grasses all skidtrails in highly erodible materials, particularly on moderate to steep slopes (applies to areas of high fisheries values).
- g. Remove log culverts or "ice bridges" prior to spring melt, if blockage or scouring is probable.

In the Centennial Creek cutting units, skidtrail layout was left to the discretion of contractors and many areas were contoured to slopes, particularly on the south and north slopes in upper Centennial Creek, but contouring was not practiced as frequently in the sloping lacustrine deposits near Karolyn Creek. Although operations were terminated during unstable periods no attempts were made to install water bars or revegetate sloping, erodible skidtrails and landings.

4. Streamside Harvesting Practices

4. Streamside harvesting practices

The channels of tributary streams that were associated with clearcutting also contributed sediment downstream to Centennial Creek. Diversions and streambank slumpage (excluding scouring from the channel bottom) from in-stream falling and skidding caused transport of an estimated 26 m^3 of sediment per 100 m of stream from a winter-logged unit at lower Rosanne Creek. Prescription of appropriate streamside logging practices within cutting permits would minimize channel erosion. Three alternative practices depending on stream value, terrain and landform, erosion potential, tree maturity and aspect, and timing of logging are:

- a. Directional falling and skidding practices.
- b. Selective strip practice.
- c. Reserve strip practice.